

# Full-Scale Test Evaluation of Aircraft Fuel Fire Burn-Through Resistance Improvements

Timothy R. Marker and Constantine P. Sarkos  
Federal Aviation Administration, William J. Hughes Technical Center

## Abstract

Fuselage burn-through refers to the penetration of an external post-crash fuel fire into an aircraft cabin. The time to burn-through is critical because, in a majority of survivable aircraft accidents accompanied by fire, ignition of the cabin materials is caused by burn-through from burning jet fuel external to the aircraft. There are typically three barriers that a fuel fire must penetrate in order to burn-through to the cabin interior: aluminum skin, the thermal acoustical insulation, and the interior sidewall/floor panel combination. The burn-through resistance of the aluminum skin is well known, lasting between 20 to 60 seconds, depending on the thickness. Thermal acoustical insulation, typically comprised of fiberglass batting encased in a polyvinylfluoride (PVF) moisture barrier, can offer an additional one to two minutes if the material is not physically dislodged from the fuselage structure. Honeycomb sandwich panels used in the sidewall and floor areas of transport aircraft offer a substantial barrier to fire; however, full-scale testing has shown that a large fire can penetrate through other openings, such as the seams between sidewall panels, window reveals, and floor air return grilles. Of the three fire barriers, research has shown that large increases in burn-through resistance can be gained by using alternate materials in place of the existing fiberglass based thermal acoustical insulation. In particular, a heat-treated, oxidized polyacrylonitrile fiber was shown to increase the burn-through resistance by several minutes over current insulation, offering potential life savings during a post-crash fire accident in which the fuselage remains intact.

## Introduction

### Background

In a majority of survivable accidents accompanied by fire, ignition of the interior of the aircraft is caused by burning jet fuel external to the aircraft as a result of fuel tank damage during impact. One important factor to occupant survivability is the integrity of the fuselage during an accident. There are typically two possibilities which exist in an aircraft accident: 1) an intact fuselage, or 2) a crash rupture or an emergency exit opening occurs, allowing direct impingement of external fuel fire flames on the cabin materials. Based on a consideration of past accidents, experimental studies, and fuselage design, it is apparent that the fuselage rupture or opening represents the worst case condition and provides the most significant opportunity for fire to enter the cabin (Sarkos 1988). Past Federal Aviation Administration (FAA) regulatory actions governing interior material flammability were based on full-scale tests employing a fuel fire adjacent to a fuselage opening in an otherwise intact fuselage. This scenario, in which the cabin materials were directly exposed to the intense thermal radiation emitted by the fuel fire, represented a severe, but survivable, fire condition against which to develop improved standards. However, in some crash accidents, the fuselage remained completely intact and fire penetration into the passenger cabin was the result of a burn-through of the fuselage shell (Sarkos 1990). At least 10 transport accidents involving burn-through have occurred in the last 20 years, five in which the rapid fire penetration of the fuselage was a primary focus of the investigation: Los Angeles 1972; Malaga 1982; Calgary 1984; Manchester 1985; and Anchorage 1987.

## Accident Data

An example of an accident involving fuselage burn-through with a large loss of life occurred in Manchester, England in 1985. During this accident, a B-737 was approaching takeoff when it experienced an uncontained engine failure, propelling pieces of the engine into the wing, and subsequently rupturing the wing fuel access door area. The takeoff was aborted. As the airplane decelerated, leaking fuel ignited and burned, erupting into a large ground fire after the plane came to rest. Although the fire fighting response was practically immediate, 55 occupants perished from the effects of the fire. In this accident, it was believed that the external fire caused a very rapid burn-through of the lower fuselage skin and quickly involved the cabin furnishings by gaining entry through the baseboard return air grills (reference Air Accidents Investigation Branch 1988 report).

Although fire can penetrate into the passenger compartment by a variety of paths, including the windows, the sidewall (above floor), cheek area (below floor), cabin floor, and baseboard return air grilles, there is no set pattern based on past accidents or experimental test data to indicate which areas are the most vulnerable. Testing had been performed on the individual components (aluminum skin, windows, thermal-acoustical insulation, and interior sidewall panels) but had not been done on the complete fuselage shell system in which fire penetration paths and burn-through times could be observed. For this reason, an initial test program was conducted to determine these mechanisms and the likely time framework required for burn-through to occur.

## Experimental

### Initial Fuselage Testing

To better understand and quantify the fuselage burn-through problem, the FAA conducted a series of full-scale tests by subjecting surplus aircraft (DC-8 and Convair 880) fuselages to 37 square meter fuel fires (20 x 20 feet). The fuel fires were set adjacent to intact fuselage sections instrumented with thermocouples, heat flux transducers, and cameras to determine penetration locations, fire paths, and important event times (Webster, 1990). Several major findings were concluded in terms of the likely entrance paths of the fire and the time required to involve the cabin interior materials. The tests indicated that the aluminum skin provides protection from a fully developed pool fire for 30 to 60 seconds and that the windows are effective flame barriers until they shrink due to the radiant heat of the fire and fall out of place, allowing flame penetration. These findings were consistent with data obtained during the investigation of the above mentioned accidents. The tests also highlighted the importance of thermal-acoustical insulation in preventing fire penetration. It was observed that the insulation can provide a significant delay in the burn-through process, provided it remains in place and is not physically dislodged from its position by the updrafts of the fire. Several other findings were highlighted, including the ability of the flames to gain access to the cabin by first penetrating into the cheek area and then progressing upward through the floor air return grills. The information obtained during this test

project was used as a basis in the development of a full-scale burn-through test rig.

### Development of a Full-Scale Burn-Through Test Rig

The next phase of the program involved the development of a test apparatus by which improvements could be evaluated under realistic conditions. The construction of a full-scale test rig was the most practical approach that would allow repetitive testing and systematic evaluation of singular components. To accommodate this, a 6.1 meter (20 foot long) steel test rig was fabricated, and a 707 fuselage was cut in half, and the test rig was then inserted between the two fuselage halves (Figure 1). This test rig had a 12 x 8 foot section of the outer skin removed which could be mocked-up with aluminum skin, thermal acoustical insulation, floor and sidewall panels, carpet, and cargo liner. The mocked-up test rig extends beyond the 3.0 meter (10 foot long) fire pan, eliminating any edge effects or mating problems that might occur if the test rig/707 fuselage seams were in direct exposure to the fuel fire. Measurements of temperature, smoke, and fire gases ( $\text{CO}$ ,  $\text{CO}_2$ , and  $\text{O}_2$ ) are taken inside the test rig, along with video coverage at several locations to determine exact burn-through locations and times.

### Characterization of the Fuel Fire

Prior to commencement of the mock-up tests, the fuselage exterior surface was instrumented with thermocouples, calorimeters, and radiometers in an effort to quantify test fires at different fuselage locations. During past test programs, ground fires of this size were ignited next to fuselages at the cabin floor level and adjacent to a Type A opening to simulate an open escape exit or fuselage rupture. It was determined from these earlier tests however, that from a burn-through standpoint, a more severe condition results when the fire is beneath the fuselage, allowing the higher temperatures of the upper flame area to come in contact with the lower fuselage. Two fire pan locations were tested, and the location that provided the more severe results of the two was established as the standard fire condition for future material mock-up tests. These tests also provided information on the radiative and convective heat flux produced by fire of this size. Typically, the fuselage skin is subjected to maximum heat fluxes of between 15.9 and 18.2  $\text{W/cm}^2$  (14 and 16  $\text{Btu/Ft}^2 \text{ sec}$ ) when measured with a Ther-

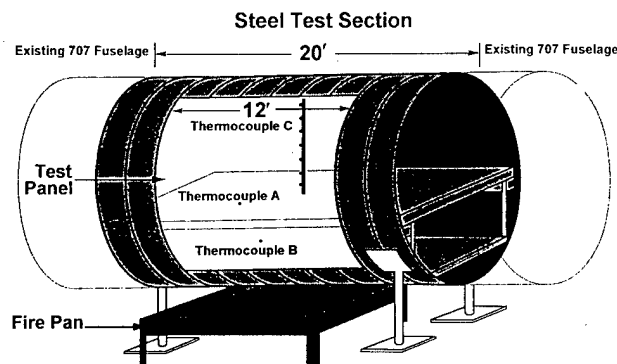


Figure 1. Fuselage burn-through test rig.

moguage calorimeter (combined radiative and convective heat flux). By comparison, a Thermoguage radiometer with a 136 degree angle of incidence (radiative heat flux only) reached approximately  $13.6 \text{ W/cm}^2$  ( $12 \text{ Btu/Ft}^2 \text{ sec}$ ).

### Initial Baseline Tests

In order to evaluate potential improvements in materials and systems for better resistance to fuel fire penetrations, a baseline test arrangement was established using in-service materials. An aluminum skin section measuring 2.44 m high by 3.66 m wide (8 x 12 feet) was installed where the original skin of the test rig was removed. It consisted of two sheets of 0.16 cm (0.063 inch thick) Alclad 2024 T3 aluminum heli-arc'd together. The aluminum panel extended from the lower fuselage quadrant up to the window level and was mounted to the test rig stringers and ribs using steel rivets to reduce the potential for separation during testing. The remaining area of the test rig was covered with 22 gauge sheet metal. The first several tests utilized custom made insulation batting, consisting of Owens-Corning Aerocor fiberglass insulation encapsulated in Orcon brand heat shrinkable metallized polyvinylfluoride (PVF) film, type AN-18R. The insulation and batting material was sized to fit in the spaces outlined by the vertical formers and the horizontal stringers of the test rig. The insulation bats spanned the entire area of the aluminum skin, 2.44 x 3.66 m (8 x 12 feet). In the test rig cargo compartment, 0.033 cm (0.013 inch thick) Conolite BMS 8-2A fiberglass liner was installed in both the ceiling and sidewall areas facing the fire and held in place by steel strips of channel screwed into the steel frame of the test rig. An M.C. Gill "Gillfab" 4017 honeycomb floor panel measuring 1.22 x 3.66 m (4 x 12 feet) was installed in the test rig cabin area and covered with FAA approved aircraft quality wool/nylon carpet. The remaining test rig cabin floor area consisted of corrugated sheet steel. Interior sidewall panels from an MD-80 aircraft were used; these panels utilized an aluminum substrate which did not meet the current FAA fire test regulations regarding heat release rate. The outboard cabin floor area contained steel plating with 7.62 cm (3 inch diameter) holes to simulate the venting area between the floor and cheek area. Additionally, an aluminum mesh was installed below the sidewall panels to simulate the baseboard air return grills. In general, the major components of a typical aircraft fuselage were represented in the test rig.

During the first test, the fire burned through the aluminum skin within 30 seconds and quickly displaced or penetrated the thermal-acoustical insulation bats, allowing flames to enter the cheek area within 40 seconds. The actual point of first penetration into the cabin was difficult to decipher, since the fire propagated both the sidewall panels and floor return air grills within a short time of one another. Early indications pointed to the lack of complete coverage by the 2.54 cm (1 inch thick) thermal-acoustical insulation, which had been attached to the test rig by loosely packing it into the spaces between the stringers and formers and duct taping all edges. Since a major objective is to determine the effectiveness of the thermal-acoustical insulation when it is not physically displaced, efforts were made to better secure the batting material. The thickness of the insulation was also increased for the next test,

as an inspection of several surplus fuselages revealed that the insulation was at least seven centimeters thick in the sidewall area (the insulation actually becomes much thinner at the extreme lower section of the fuselage, due to lesser acoustical requirements). Although the thickness of insulation varies slightly between aircraft, it was found to be at least several plies thick in the corresponding areas of the test fuselage where the fire had penetrated during the first test. The results of the next test were similar to the first in terms of fire propagation paths and burn-through times, but again, it was very difficult to pinpoint the actual path taken because of the visual obstruction due to the placement of the sidewall panels and cargo liner. In order to better understand the burn-through mechanism, the subsequent tests were conducted without sidewall panels, cargo liner, and floor panels to allow greater visualization of the burn-through point and time.

### Evaluation of Current Insulation Materials

An evaluation of current fiberglass insulation was conducted in which the effects of the thickness and the method of installation on burn-through time were investigated. A surplus of the Aerocor type insulation material allowed for the conduct of several tests using varying layers. As shown in Figure 2, the first three Aerocor tests utilized 7.62 cm (3 inch thick) Aerocor encased in a heat shrinkable metallized polyvinylfluoride film. The method of Aerocor attachment was refined during each test, as the fire visibly dislodged the batting materials during the first and second tests causing burn-through in 52 and 75 seconds. During the third Aerocor test, heavier spring clips were utilized and installed around the entire perimeter of each insulation bat, which proved to be a very effective attachment system. A fourth Aerocor test was conducted using an additional one inch layer of insulation, which provided an additional 12 seconds. Thus, secured insulation provided about 45 seconds of additional protection after the aluminum skin melted. As a point of clarification, the time to burn-through is determined by visual observation of video cameras located at

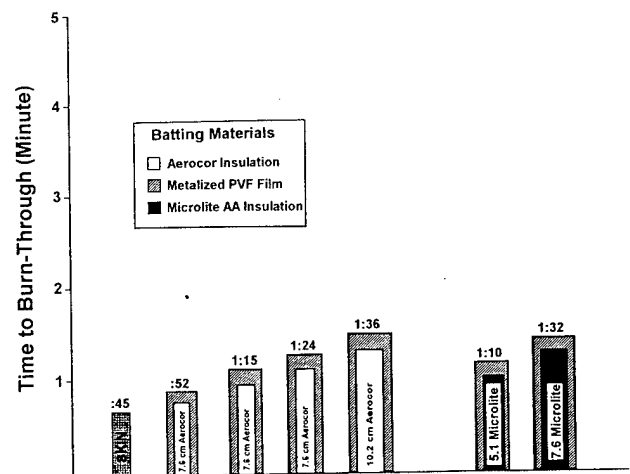


Figure 2. Fuselage burn-through resistance current fiberglass/PVF insulation bags.

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various places in the test rig interior. The actual time is somewhat subjective, since the exact time and location are not always clearly defined.

Since the Aerocor is a somewhat dated material, additional tests were conducted using Microlite AA insulation which is currently used on most transport category aircraft. As shown, there was only a marginal increase in the burn-through resistance offered by the three inch Microlite material (1 minute 32 seconds versus 1 minute 24 seconds using a 7.62 cm thickness of Aerocor). The test rig burn-through times compared favorably with past tests using surplus aircraft (Webster, 1994) where flame penetration was observed in approximately 2 minutes 30 seconds. Assuming that the sidewall panels, flooring, and cargo liner in the surplus aircraft likely provided an additional minute of protection, it was concluded that the mock-up tests were a reasonable representation of actual crash fire conditions.

With a realistic and repeatable test condition and the burn-through resistance of current materials defined, improvements in burn-through resistance were evaluated. Considering the thermal acoustical insulation system only, there are two distinct possibilities: 1) modification/enhancement of existing insulation materials and 2) replacement of the current fiberglass insulation with a more fire resistant type.

## Evaluation of Modified Current Insulation Materials

The previous burn-through evaluation of existing materials revealed that the metallized polyvinylfluoride film allowed rapid fire propagation from the out-board face of the insulation bat to the in-board face. A candidate replacement film is polyimide (Kapton) which has low flammability/smoke emission characteristics. The use of polyimide or Kapton film as a moisture barrier for commercial aircraft insulation is not new, having been introduced on the L-1011. The Kapton film exhibited improved flame resistance as shown in Figure 3. For

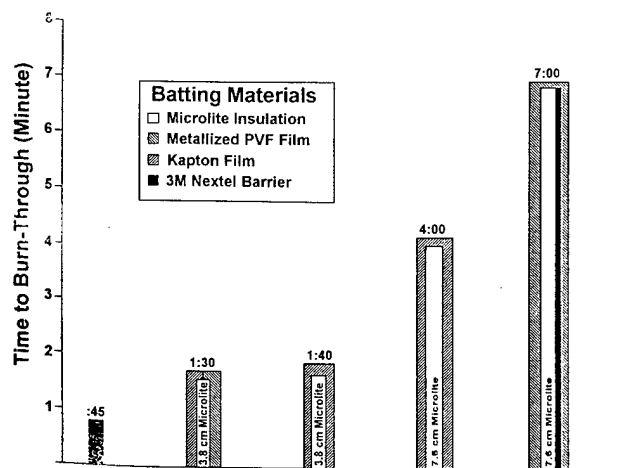


Figure 3. Fuselage burn-through resistance improvements with current fiberglass insulation.

example, comparable burn-through times were exhibited when Kapton was used with half the thickness of insulation (3.81 cm [1.5 inches] as compared to 7.62 cm [3 inches] of insulation with polyvinylfluoride, Figure 2). The most notable test results occurred when 7.62 cm (3 inch thick) Microlite AA was used in conjunction with the Kapton film. This combination was capable of resisting burn-through for four minutes, or an increase of approximately 2 minutes 30 seconds over the identical thickness of insulation material with the polyvinylfluoride film.

A thin fire resistant layer of ceramic fiber material known as Nextel™ was also evaluated. Developed by the 3M Company, Nextel™ ceramic oxide fibers are continuous, polycrystalline metal oxide fibers suitable for producing textiles without the aid of other fiber or metal inserts. The polycrystalline fibers are typically transparent, nonporous, and have a diameter of 10-12 μm. The continuous nature and flexibility of the ceramic oxide fibers allows them to be processed into a variety of textile shapes and forms using conventional weaving and braiding processes and equipment. In this particular arrangement, a nonwoven mat of Nextel™ was being tested full-scale to determine its effectiveness when used as an additional barrier to the existing insulation.

During the test, the Nextel™ was placed inside each of the insulation bats and then encapsulated with the standard polyvinylfluoride moisture barrier film. The Nextel™ was installed

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on the out-board face of the insulation bats (within the film) to form a flame propagation barrier between the external flames and the interior of the fuselage. The insulation bats, along with Nextel™ fiber were clamped in place around the perimeter; the clamping also held the Nextel™ in place. This arrangement was very effective, preventing burn-through for nearly seven minutes; although there were visible flames on the backface of the insulation bats, it was difficult to determine what was igniting due to the elevated temperatures (Figure 3). A majority of the Nextel™ was revealed to have remained in place following a post test inspection, however, in several areas it was clear that the Nextel™ had opened, allowing flames to penetrate.

## Evaluation of Alternative Insulation Materials

Another series of tests were conducted using an alternate insulation material known as Curlon®, a heat treated, oxidized, polyacrylonitrile fiber (OPF) produced by RK Carbon International, Ltd. Curlon® has a permanent crimp or waviness incorporated into the fiber which aids in the manufacture of lightweight battings used primarily for aircraft insulation. RK Carbon International manufactures the OPF (Panox®) which is then converted in a proprietary heat treating process to form the non-melting, non-burning gray-black Curlon® fiber. Curlon® contains about 70 percent carbon, 20 percent nitrogen, and 10 percent oxygen. It has a diameter of about 8 microns and is considered non-irritating to the skin. Curlon® is also a nonconductor and chemically resistant.

The insulation system incorporating Curlon® is marketed by Orcon Corp. under the tradename Orcobloc™, formerly FB-300, and is unique in that it could potentially be used as a drop-in replacement for the current fiberglass insulation (i.e., it possesses qualities similar to fiberglass for the intended use in aircraft applications). Early versions of the FB-300 were somewhat inferior to the current fiberglass materials in terms of sound absorption and noise attenuation, which is the primary purpose of insulation in the window belt area. The fabrication process was altered slightly to produce a better performing material known as FB-300 SA (superior acous-

tics). Both materials were tested extensively in the full-scale test rig; the results are shown in Figure 4. The Curlon® material was extremely effective at resisting flame penetration for at least five minutes during several tests. Early concerns over the decomposition products yielded when Curlon® is exposed to elevated temperatures were dispelled, as only trace amounts of hydrogen cyanide were collected during several of the tests.

The performance of the polyvinylfluoride film moisture barriers was also more evident during these tests since the Curlon® material stayed in place for extended periods of time. In doing so, it was clear that the fire was actually propagating along the thin film, around the periphery of the individual bats to the back face. This could present a problem when interior sidewall panels are installed since the burning film may be enough of an ignition source to involve the panels despite the fact that the insulation had not been penetrated. Two additional tests were conducted using Kapton film with the Curlon® for an additional improvement. The backface of the Kapton film did not ignite and was clearly far superior to the polyvinylfluoride film in this respect.

Another alternate material tested was a rigid polyimide foam supplied by the Imi-Tech® Corp. known as Solimide® AC-430. AC-430 has excellent sound absorption, and good thermal insulating properties, but does not compress like fibrous insulation, allowing superior R-values to be achieved. The primary advantage of the foam is its rigidity, enabling the design of an insulation system which spans between aluminum formers (i.e., it does not allow the insulation to directly contact the inside surface of the outer skin) thereby reducing moisture entrapment from condensation. This has been a significant problem with existing insulation systems as they inevitably absorb moisture when in continuous contact with the aluminum skin. Variants of this product are currently in use in the belly area of some newer Boeing commercial aircraft. As shown in Figure 5, three tests were run using rigid polyimide foam as the base material.

During the first test, insulation bats comprised of 7.62 cm (3 inch) of Solimide® rigid foam heat sealed in a bag of Insulfab® reinforced polyimide film supplied by Facile Holdings, Inc.

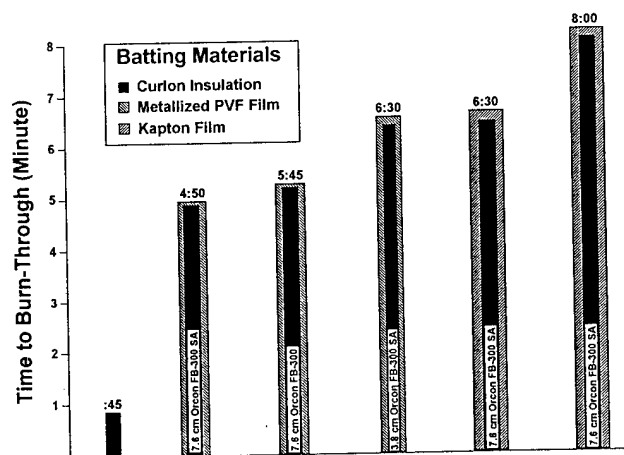


Figure 4. Fuselage burn-through resistance Curlon® insulation.

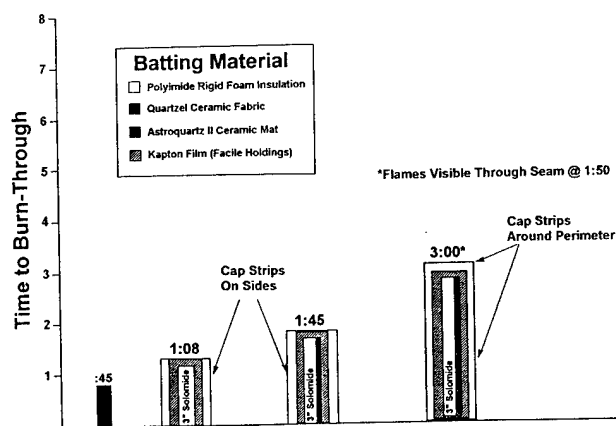


Figure 5. Fuselage burn-through resistance polyimide foam insulation.

Table I. Burn-Through Material Properties

Insulation Batting Materials					
Material Name	Material Type	Density (kg/m <sup>3</sup> )	Density (lb/ft <sup>3</sup> )	Fiber Diameter (μm)	Tensile Strength (GPa)
Aerocor Type PF105WL	Glass Fiber	6.7	0.42	1.5	—
Microlite AA	Glass Fiber	5.5 to 9.6	0.34 to 0.60	1.5	—
Curlon®	Heat Treated, Oxidized, Polyacrylonitrile Fiber	3.2 to 6.4	3.2 to 6.4	8	0.65
Solimide®	Right Polyimide Foam	5.3	5.3	n/a	4 x 10 <sup>-5</sup>
Fire Barriers					
Nextel™	Ceramic Fiber	2,700	168	10 to 12	1.7
Quartzel®	Vitrous Silica Wool	17	1.1	9	—
Astroquartz II®	Quartz Fabric	890	56	9	6.0
Insulation Films					
Material Name	Material Type	Film Thickness (μm)	Skrim Material	Film + Skrim Weight (g/m <sup>2</sup> )	Tensile Strength (GPa)
AN-18R	Metallized Polyvinyl Fluoride Film	50	Nylon	30 ± 5	—
KN-80	Polyimide (Kapton) Film	25	Nylon	46.5	—
Insulfab 121-KP	Polyimide (Kapton) Film	25	Nylon	68.6	—

were installed. The insulation system allowed burn-through to occur at 1 minute 8 seconds, approximately 20 seconds less than fiberglass batting. In an effort to extend the burn-through time, Quartzel®, a vitreous silica wool barrier, was placed in the insulation bats, not unlike the earlier fiberglass enhanced tests with Nextel™. The use of the Quartzel® improved the burn-through resistance of the rigid foam material, but the system was still much less effective than both the Nextel™ enhanced fiberglass system and the Curlon®. The weakness appeared to be at the seam location, which allowed flames to propagate to the in-board face early in the test. After reinspection of the video coverage, it was determined that the system was, in fact, failing at the seam, rather than because of burn-through of the material. In an effort to rectify the problem, horizontal "cap strips" were used in addition to the vertical cap strips already used in the previous tests to hold the insulation to the test frame. A third test was conducted with this arrangement and the use of another fire blocking material known as Astroquartz II®, a quartz fabric. The additional horizontal cap strips aided in extending the burn-through time, but, it was still not close to the level attained by the other systems. A future test has been planned to repeat the third test using an installation that would allow direct attachment of the fire blocking material to the test frame, similar to the attachment method used during the Nextel™ enhanced test. Known properties of the materials used in the full scale tests are included in Table I.

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## Development of a Medium Scale Test Rig

Much of the research on fuselage burn-through was a joint effort between the FAA and the United Kingdom Civil Aviation Authority (CAA). In particular, the FAA was responsible for the development of the full-scale test apparatus described above, while the CAA had tasked Darchem Engineering to develop a medium-scale test apparatus. During the early phase of this joint research program, it was determined that the development of a small or medium scale burn-through test facility could be beneficial in investigating the problem of burn-through. A laboratory test facility which could replicate the full-scale conditions allows for quick and inexpensive testing of improved materials and/or systems and also serves as a screening device for evaluating new materials under consideration. To date, Darchem has developed the testing apparatus and has logged hundreds of hours of testing at the Faverdale Technology Centre (FTC) in Darlington. The medium scale facility has proven to be an effective screening tool for materials under consideration and enables new protection systems to be developed. It is anticipated that the apparatus will compliment research conducted in the FAA full-scale test rig in order to bring about improvements in the burn-through resistance of fuselages.

## Conclusions

### Summary of Results

From the results of the initial full-scale surplus aircraft tests, as well as the several series of tests completed in the burn-through test rig, it is evident that the aluminum skin provides 30 to 60 seconds of protection prior to melting and, subsequently, allowing flame impingement on the thermal-acoustical insulation. The aluminum skin currently in use offers little opportunity for fire hardening and will likely be used in next generation aircraft to a large extent. This leaves the focus of extending the burn-through resistance on the thermal-acoustical insulation and the floor/sidewall panel combination and related components. Full-scale fire tests have shown that appreciable gains in burn-through resistance can be achieved by either protecting or replacing the current fiberglass thermal acoustical insulation. As shown in Figure 6, using a Kapton film bagging material in place of the current polyvinylfluoride film alone may provide an additional three minutes of protection. Also, a lightweight ceramic matt placed on the out-board face of the fiberglass insulation prevented burn-through over a nearly seven minute test duration. The most effective replacement combination was a heat stabilized, oxidized polyacrylonitrile fibrous material (Curlon<sup>®</sup>) encased in a polyimide film. This combination resisted burn-through for eight minutes. The Curlon<sup>®</sup> did not ignite or burn when subjected to the fuel fire. The Kapton film prevented any flame spread on the in-board face. Moreover, the Curlon<sup>®</sup> has the ability to be used as a direct drop-in replacement for the currently used material.

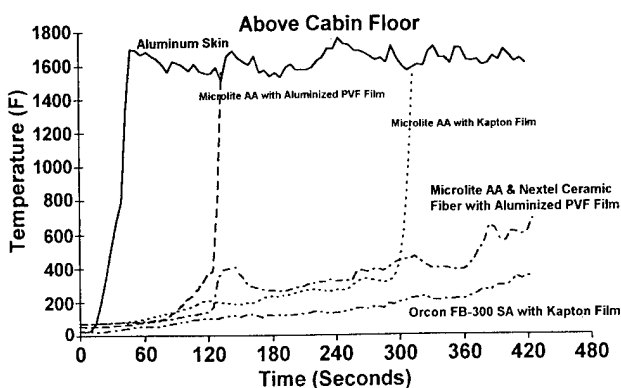


Figure 6.

## Future Considerations

### Air Return Grilles

Once a fire penetrates the thermal acoustical insulation, it can quickly gain access to the cabin via the air return grill system. The use of intumescent coatings may be a simple concept for delaying grill penetration (and could be used for the enhancement of the backface of interior panels to prolong their burn-through capabilities).

### Aluminum Versus Steel Structure

Although the enhanced and alternate insulation materials tested produced results which were very promising, it should be noted that the tests may be biased due to differences between the test rig and an actual aircraft fuselage. The most significant is the use of a steel structure in the test rig, which will not collapse during a test. For this reason, tests will be conducted with actual aircraft structure to investigate the effect of the aluminum structure on burn-through resistance improvement.

### Attachment Methods

In conjunction with the tests using aluminum aircraft structure, a thorough investigation of the attachment methods will be conducted. The method of attachment is critical if burn-through resistance improvements are to be realized. It may be possible to obtain several minutes additional protection from burn-through using current materials by simply using attachment clips that won't melt and fail during exposure to external fires. Currently, there are several different methods of insulation bat attachment, most of which consist of thermoplastic washer type fasteners. In addition, many of the current insulation bats are attached directly to the backface of the fuselage skin via fasteners mounted using pressure sensitive adhesives which will quickly fail when heated from fuel fire exposure.

### Windows

The cabin windows must also be protected against burn-through by an external fuel fire. The pressure pane located on the outermost surface is constructed of stretched acrylic which shrinks when exposed to heat and flames. Once this occurs, the pressure pane falls out of place, allowing the flames to impinge on the fail-safe pane which will similarly fail in short duration.

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Airframe manufacturers would be reluctant to modify the pressure pane; however, it is possible that the fail safe pane could be enhanced to contribute to the improved fire resistance of the aircraft fuselage.

### Totally Composite Fuselage

Another area that will be studied is the burn-through resistance of a composite skin fuselage. The use of composites in transport category aircraft has grown steadily due to their high strength and low weight. The fuselage skin of the High Speed Civil Transport (HSCT) will likely be constructed of a composite material which requires an assessment of its performance when exposed to a large fuel fire. From a burn-through standpoint, a composite fuselage would likely offer greater burn-through protection than aluminum. However, there is concern over the potential for toxic and combustible gases being released during flame exposure, which could present a hazard to escaping occupants. Whether or not this is a real concern will be determined in the full-scale test rig by replacing the aluminum skin with composite structure and measuring the resultant gases within the cabin.

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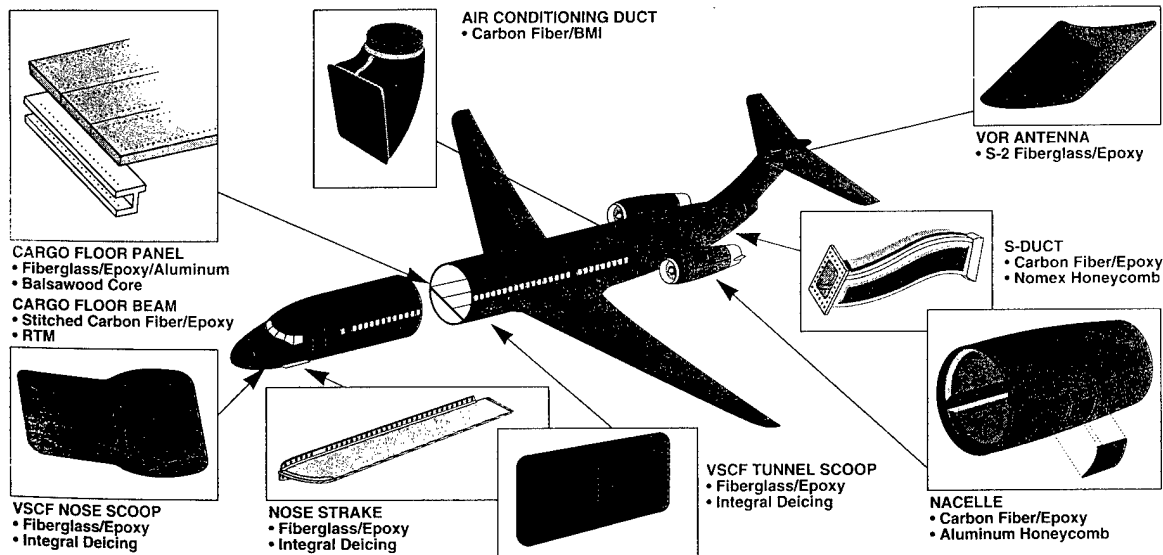
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